Sports nutrition interventions: a systematic review of behavioural strategies used to promote dietary behaviour change in athletes

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Abstract

Designing and implementing successful dietary interventions is integral to the role of sports nutrition professionals. Despite this, no review has evaluated sports nutrition interventions and consequently their active ingredients are not defined. This systematic review aimed to identify the behavioural strategies used in sports nutrition interventions and to explore any relationship between the strategies employed and intervention effects. SPORTDiscus, MEDLINE, CINAHL, PubMed, and SCOPUS were searched for behavioural interventions that aimed to change athletes' dietary behaviour. Behavioural interventions were eligible for inclusion provided pre and post-measures of dietary intake were reported. The protocol adheres to Preferred Reporting Items for Systematic reviews and Meta-Analyses Protocols (PRISMA-P). Each study was coded against the "Template for Intervention Description and Replication" (TIDieR) checklist and the Behaviour change technique (BCT) taxonomy v1. Only 19 BCTs are currently employed within sports nutrition interventions suggesting that 80% of the available BCTs are not being used. Only three studies were theory informed and the standard of reporting across all studies requires substantial improvement. However, the majority of studies reported changes in athletes' dietary behaviour post-intervention. This review highlights an absence of evidence-informed approaches defining the professional practice of sports nutrition and illuminates a limited application of BCTs within the sports nutrition field. Consequently, the authors provide a framework and guide for intervention development to increase rigour and effectiveness of future sports nutrition interventions. PROSPERO registration number: CRD42018072283.

Key words: Behaviour change techniques, dietary intake, nutritional program

Introduction

Historically, research in the field of sports nutrition has been defined by studies seeking to strengthen our understanding of nutritional physiology and generate the evidence-base underpinning good practice guidelines (Burke et al., 2018; Jeukendrup, 2017). However, such research is meaningless if the athlete population does not implement the findings in their day-to-day practice. Over the past decade, there has been an exponential increase in the number of publications within the field of sports nutrition but poor adherence to sports nutrition guidelines by athletes is frequently reported (Ali, Al-Siyabi, Waly, & Kilani, 2015; Ghloum & Hajji, 2011; Krempien & Barr, 2011). Implementation science is also noticeably absent in the field and there is a lack of research evaluating the effectiveness of nutrition education and behaviour change interventions in sports nutrition. Developing a better understanding of effective sports nutrition interventions is vital to improve the design and content of future interventions seeking to enhance the performance and protect the health of athletes.

A previous systematic review has considered the effectiveness of nutrition education programmes in athletes (Heaney, O'Connor, Michael, Gifford, and Naughton (2011), reporting a weak ($r < .44$) positive association between knowledge and dietary intake in five of the nine studies investigating this relationship. Whilst important implications arose from Heaney and colleague's review – including the need for further research in the field - it is apparent that education alone is insufficient to change behaviour (Conner & Norman, 2015; Kelly & Barker, 2016; Ogden, 2016). Instead, theoretically driven programmes that include behavioural science need to be designed and implemented, and thus a broader perspective on nutritional interventions and their effectiveness is warranted (Atkins & Michie, 2013).

Behavioural science acknowledges that behaviour change interventions are determined by numerous components. These include techniques to facilitate behaviour change and the contextual factors that must be taken into account when delivering those techniques (Michie,

Fixsen, Grimshaw, & Eccles, 2009). Specifically, behaviour change techniques refer to the smallest observable and replicable components that may bring about change, known as "active ingredients" (Michie & Johnston, 2012). Researchers working in implementation science suggest that theoretical and methodological clarity can accelerate the identification of effective behaviour change interventions and the development of evidence-based practice (Michie & Abraham, 2004). Thus, adopting a standardised assessment process to identify techniques and procedures can improve the quality of intervention evaluations. However, to our knowledge there has been no systematic review identifying the behavioural strategies used in sports nutrition behavioural interventions.

Newer paradigms within systematic reviewing focus on understanding how and why interventions work to identify their critical components (Cradock et al., 2017; Govender, Smith, Taylor, Barratt, & Gardner, 2017). However, the active ingredients of sports nutrition interventions are still to be ascertained. The Behaviour Change Technique (BCT) taxonomy v1 (BCTTv1) (Michie et al., 2013) includes 93 items that allow the active ingredients of interventions to be systematically described, reviewed, and replicated. This review is the first in the area of sports nutrition interventions to investigate behaviour change using this taxonomy (Michie et al., 2013). BCTs are mapped to the COM-B model which posits that capability (physical and psychological), opportunity (social and physical), and motivation (reflective and automatic) drive behaviour (Michie, Stralen, Maartje, & West, 2011). To develop capability, opportunity and motivation in relation to a specific behaviour certain BCTs can be applied (Cane, Richardson, Johnston, Ladha, & Michie, 2015). Consequently, Michie and colleagues argue behaviour is complex and we need to understand behaviour before appropriate intervention (Michie, Atkins, & West, 2014).

Alongside the application of theory and BCTs, Michie, Fixsen, et al. (2009) strongly advocate that intervention designers would also benefit from understanding the contextual

factors that determine intervention effectiveness, such as mode of delivery, procedures, duration and frequency. Despite The UK Medical Research Council's call for precise detail in intervention descriptions (Craig et al., 2008), this level of detail is rarely reported across behaviour change interventions, which is problematic (Michie, Fixsen, et al., 2009). Without a full and detailed description of the components of an intervention we are unable to determine what was actually implemented, allow replication in other settings or interpret the findings and delineate similar interventions from one another (Cotterill et al., 2018). The "Template for Intervention Description and Replication" (TIDieR) (Hoffmann et al., 2014) allows for a systematic description of interventions using a 12-item checklist. This details the why, what, who, where, and how of intervention delivery. Although this checklist is now widely used in health research (Cotterill et al., 2018) it has not been used in the sports nutrition field.

This comprehensive and theory-informed review aimed to identify the specific BCTs reported in interventions to improve the dietary behaviour of athletes and, where possible, explore the relationship between the presence of BCTs and intervention effectiveness. To our knowledge, this is the first systematic review to evaluate the behavioural strategies used within sports nutrition interventions and assess the evidence using the BCTTv1 and TIDieR checklist. Precise specification of intervention characteristics within sports nutrition will help build cumulative evidence towards delivering effective, replicable interventions.

Methods

This review was performed in accordance with the PRISMA guidelines (Moher, Liberati, Tetzlaff, Altman, & The, 2009; Welch et al., 2012) (Additional file 1: 1.1) and was prospectively registered with the PROSPERO database (registration number CRD42018072283).

Literature search

Searches were conducted on the electronic databases SPORTDiscus, MEDLINE, CINAHL, PubMed, and SCOPUS. The original search was conducted in January 2017 and repeated again in September 2018 to retrieve newly published articles. The search strategy was developed in conjunction with a subject librarian following an initial scoping exercise. The search was limited to English language, peer reviewed, and stemmed from three themes: (1) athlete, (2) dietary behaviour, and (3) nutritional intervention. The reference list of a systematic review was manually searched for eligible papers (Heaney et al., 2011).

Inclusion criteria

For inclusion, studies were required to report the outcome of a coordinated set of activities designed to improve athletes' dietary behaviours in a sports context. To yield sufficient evidence, interventions were delivered in various settings (e.g., universities, training centres), using multiple modes of delivery (e.g., face-to-face, video/DVD), across a variety of duration and frequency (from a single point of contact to intensive long-term interventions). Studies that did not attempt to directly change dietary behaviour (e.g., prescribed diets within controlled environments) were excluded. In studies with more than one intervention group, the intervention that had the most components within the programme was compared with controls.

Studies were included if nutritional intake (e.g., changes in energy, carbohydrate, protein, fat, vitamin, mineral, or fluid), or a dietary behaviour (e.g., change in vegetable or fruit servings) were assessed between baseline and post intervention. Due to the heterogeneous nature of the research field, various outcome measurements were included (e.g., food records and questionnaires). Studies with a comparator were included in the review including; passive control group (e.g., no treatment or delayed treatment) or active control group (e.g., alternative behavioural approaches). Given the limited evidence-base, studies with no comparator were also included.

After executing the search strategy (Additional file 2) duplicate articles were removed using Endnote X9. Two reviewers (MB and NM) independently screened all titles and abstracts against the inclusion and exclusion criteria, retrieving potentially eligible studies. MB and NM independently assessed the retrieved full-text articles. Any disagreement over a study's eligibility were discussed with the third reviewer (SB) to achieve consensus (Figure. 1).

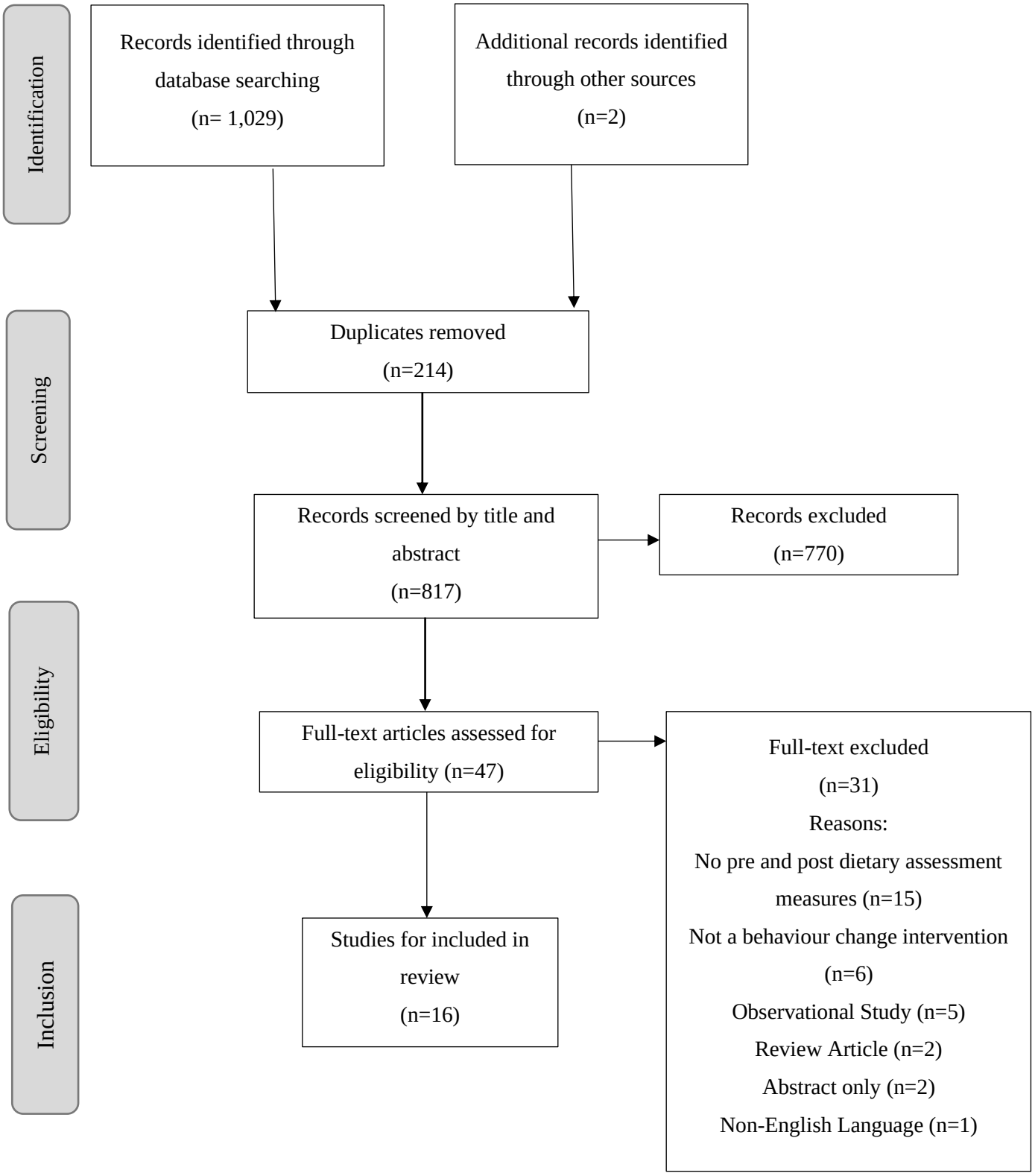

Figure 1: PRISMA flowchart showing process of study selection

Population

The study population comprised of athletes (≥13 years old) of all genders and nationalities who engaged in competitive (recreational or elite) sport (Heaney et al., 2011), including high-school, college, university, national, and professional levels. Athletes with disordered eating were excluded. All review participants were able-bodied as no studies involving Paralympic athletes were identified in the search.

Data extraction

Data extraction was conducted by the first author (MB) in an Excel data extraction form. Extracted information included; study characteristics (authors, year, journal article, country of origin, study design), participant characteristics (sport, age, gender, sample size), intervention features (theoretical approach, intervention setting, provider, procedure, materials used, frequency, and duration), and measurement descriptions (type of measurement used, and follow-up duration).

Classification of intervention content

Each intervention was categorised using Michie and colleagues (Michie et al., 2011) nine function categories which reflect the broad method through which an intervention may influence behaviour: Education, Training, Enablement, Modelling, Restrictions, Environmental Restructuring, Persuasion, Incentivisation, and Coercion. An extensive coding frame, the "Theory Coding Scheme" (Michie & Prestwich, 2010), was used to assess the extent to which behavioural interventions are theory-based. Subsequently, interventions were categorised according to Painter, Borba, Hynes, Mays, and Glanz (2008) classifications; 1) Informed by theory, 2) Applied theory, 3) Testing theory, or 4) Building or Creating theory.

Coding of behaviour change techniques

To obtain more accurate intervention descriptions and assist with BCT coding, all 16 study authors were contacted on up to three separate occasions via email requesting a copy of

the corresponding intervention manual or any additional available documents that provided further information on the content of their intervention (Lorencatto, West, Stavri, & Michie, 2012). A minimum of 14 days was left between each point of contact. Thirteen authors responded, seven sent additional materials (Figure 2), and of these seven, three were translated into English. Behaviour change techniques were coded using the BCTTv1; where applicable coding occurred separately for intervention and active control conditions. All included studies were independently coded by a sports nutritionist (MB) and a chartered sports psychologist (SB). Coders engaged in critical dialogue throughout the coding process until final consensus was reached. Both MB and SB are certified coders by Michie's taxonomy training ("BCTTv1 Online Training,"). A coding framework was developed by MB to guide the process (Additional file 1: 1.2).

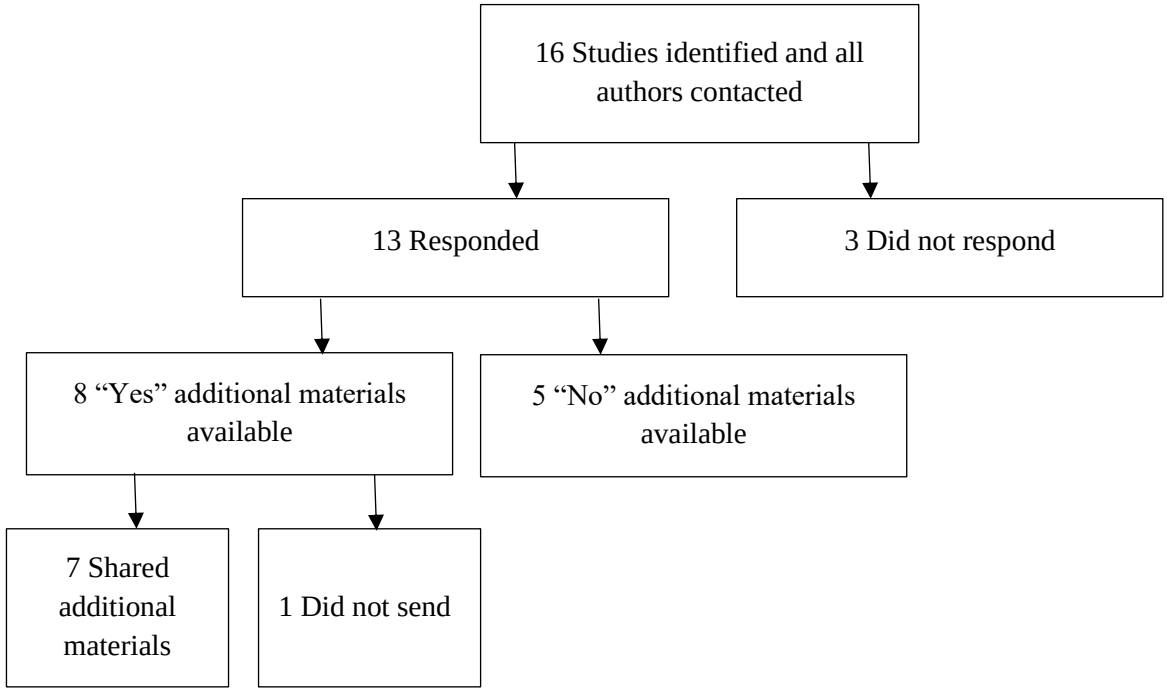

Figure 2: Response rate of contacted authors providing additional materials of intervention content.

Coding of the TIDieR checklist

For this systematic review, a risk of bias tool was considered. However, as such tools have been criticised within the healthcare setting for having limited usefulness when applied to complex interventions (Greenhalgh & Papoutsi, 2018; Pawson, Greenhalgh, Harvey, & Walshe, 2005) it was deemed inappropriate to evaluate the quality of sports nutrition interventions using such stringent assessment tools. In light of these concerns, the TIDieR checklist was used to assess intervention quality. This checklist looks beyond a simple cause and effect relationship, and instead provides a rich, detailed, and highly practical understanding of an intervention. This detail is considered to be of much more use when planning and implementing behaviour change programmes (Pawson et al., 2005).

The TIDieR checklist used within this study comprised of 12 items that are essential for accurate description and replication. All items were coded by MB as either present, unclear, or not applicable. Throughout this coding process MB and SB engaged in critical dialogue. For example, SB prompted reflexivity and regularly challenged MB's interpretations of the data by encouraging explanations for the codes generated. MB presented the findings of 8 (50%) randomly selected studies to SB who had independently coded them. This provided further opportunity for critical dialogue and any differences were discussed at length until a final decision was reached.

Data analysis and synthesis

Due to considerable heterogeneity in the included studies it was not appropriate to perform a meta-analysis. Instead, a qualitative method of narrative analysis was conducted following the Economic and Social Research Council (ESRC) Narrative Synthesis Guidance (Popay et al., 2006), describing the findings through an exploration of the data. Narrative methods are recognised as an effective approach for investigating heterogeneity across primary studies, and developing an understanding of which aspects of an intervention may be

responsible for its success (Light & Pillemer, 1984).

Results

Study selection and characteristics

Of the 1,031 articles identified from the combined searches, 219 remained after de-duplication. Forty-seven articles were retained following title and abstract screening, of which 16 studies were eligible for review. Within the 16 studies, duration and frequency of the intervention ranged from receiving a single education session (Molina-López et al., 2013) to 20 presentations over 10 weeks (Buffington, Melnyk, Morales, Lords, & Zupan, 2016). Ascertaining intervention duration and frequency was not always possible if unreported. Behaviour change maintenance was assessed in six studies (Anderson, 2010; Doyle-Lucas & Davy, 2011; Garthe, Raastad, & Sundgot-Borgen, 2011; Molina-López et al., 2013; Valliant, Pittman Emplaincourt, Kieckhaefer Wenzel, & Garner, 2012; Wenzel, Valliant, Chang, Bomba, & Lambert, 2012) and ranged from 1 week – 12 months. The studies were conducted in a diverse range of countries with the largest number from North America (8 studies), (Abood, Black, & Birnbaum, 2004; Anderson, 2010; Buffington et al., 2016; Chapman, Toma, Tuveson, & Jacob, 1997; Doyle-Lucas & Davy, 2011; Rossi et al., 2017; Valliant et al., 2012; Wenzel et al., 2012); (Table 1). The measures used to assess dietary intake varied although, three-day food records were most frequently reported (6 studies) (Abood et al., 2004; Anderson, 2010; Elias, Saad, Taib, & Jamil, 2018; Rossi et al., 2017; Valliant et al., 2012; Wenzel et al., 2012); of these only three accounted for day-to-day variability (Elias et al., 2018; Valliant et al., 2012; Wenzel et al., 2012). Outcome measures relating to dietary intake were reported across the studies at varied time intervals. The most frequently used measures were energy, carbohydrate, protein, and fat intake.

Participant demographics and characteristics

The intervention studies reported a total of 824 participants (46% females, 27% males,

and 27% unclear). Sample size ranged from 1 to 210. Athletes on average were 18.9 years (ranging from 14 – 27 years). Twenty-five sports were represented, with volleyball being the most prevalent (Anderson, 2010; Cleary et al., 2012; Valliant et al., 2012; Wenzel et al., 2012). The majority of studies involved tertiary level athletes (e.g., college or university) (Abood et al., 2004; Anderson, 2010; Buffington et al., 2016; Chapman et al., 1997; Rossi et al., 2017; Valliant et al., 2012; Wenzel et al., 2012), or national level athletes (Cleary et al., 2012; Elias et al., 2018; Nascimento et al., 2016; Nowacka, Leszczyńska, Kopeć, & Hojka, 2016; Philippou, Middleton, Pistos, Andreou, & Petrou, 2017). The remaining studies included professional athletes (Costello, McKenna, Sutton, Deighton, & Jones, 2018; Doyle-Lucas & Davy, 2011; Molina-López et al., 2013) and high-school athletes (Chapman et al., 1997).

Table 1: Study demographics, intervention characteristics, and key findings

Study demographics				Intervention characteristics				Key findings
Publication (Country)	Sport (Level)	N (gender)	Age (years)	Intervention function	Intervention procedure (As reported by author)	Mode of delivery	Frequency* (duration)	
Abood et al. (2004) (USA)	I: Football (tertiary) C: Swim (NR)	I: 15 (F) C: 15 (F)	I: 19.6 ± 1.1 C: 19.4 ± 1.2	Education, Training, and Modelling	I: Educational sessions C: Passive controls	Unclear	3 (8 wks.)	No difference in intervention group. Decreased carbohydrate[a] and fibre[a] intake in favour of the control group 2 wks. post intervention. Maintenance not assessed.
Anderson (2010) (USA)	I: Volleyball (tertiary) C: Volleyball (tertiary)	I: 8 (F) C: 8 (F)	I: 20.1 ± 0.5 C: 19.3 ± 0.5	Education	I: Individual and group feedback on dietary intake C: Passive controls	NR	NR	Increased protein[c], vitamin C[b], and calcium[b] intake. Duration post intervention unclear. Changes were not maintained 1 wk. post season.
Buffington et al. (2016) (USA)	I: Mixed (tertiary) C: Mixed (tertiary)	153 (F)	NR	Education and Training	I: Energy balance and CBT-based presentations CBT: CBT-based presentations C: Passive controls	I: Email CBT: Email	3 (10 wks.)	Decreased fat[b] intake and increased carbohydrate[b] intake in favour of the intervention group 2 wks. post intervention. Maintenance not assessed.
Chapman et al. (1997) (USA)	I: Softball (tertiary) C: Softball (tertiary)	I: 37 (F) C: 35 (F)	14 – 18 years	Education	I: Lectures C: Passive controls	NR	2 (Unclear)	Decreased energy intake[a] in favour of the intervention group. Duration post intervention unclear. Maintenance not assessed.
Cleary et al. (2012) (Hawaii)	I: Volleyball (national) C: No control group	36 (F)	14.8 ± 0.8	Education, Environmental restructuring,	Educational slideshow, individualised fluid volume and mandatory drink breaks during training.	I: Slideshow video and	2 (2 wks.)	Increased fluid volume[c] and percentage of fluid consumed to maintain body mass[d] during the intervention. Not maintained 1 wk. post intervention.

Study demographics				Intervention characteristics				Key findings
Publication (Country)	Sport (Level)	N (gender)	Age (years)	Intervention function	Intervention procedure (As reported by author)	Mode of delivery	Frequency* (duration)	
				and Enablement		face-to-face.		
Costello et al. (2018) (UK)	I: Rugby League (professional) C: No control group	1 (M)	18	Education, Coercion, Environmental restructuring, and Enablement	Oral presentation and written information to athlete and significant others. Free and discounted food and batch-tested supplements. Bi-weekly self-monitoring of body mass. Access to regular nutritional support.	Face-to-face and cellular contact.	NR (12 wks.)	Reduced alcohol[d] and free-sugar[d] intake and an increased energy[a], carbohydrates[d], fat[d], saturated fat[d], and protein[d] intake. Immediately post intervention. Maintenance not assessed.
Doyle-Lucas and Davy (2011) (USA)	I: Ballet (pre-professional) C: Ballet (pre-professional)	I: 146 (NR) C: 64 (NR)	I: 15.4 ± 0.1 C: 15.4 ± 0.1	Education	I: DVD-lectures, handouts and a worksheet task C: Delayed intervention	I: DVD and Face-to-face	2 (3 days)	Decreased candy score[d] and increased milk score[d] in favour of the intervention group 6 wks. post intervention.
Elias et al. (2018) (Malaysia)	I: Field hockey and football (national) C: Cricket and rugby (national)	I: 52 (M) C: 53 (M)	I: 18.7 ± 0.9 C: 23.3 ± 3.8	Education	I: Educational sessions C: Passive controls	Face-to-face	3 (7 wks.)	Increased energy[d], carbohydrate[a], protein[c], and fat[b] intake 1 wk. post intervention. Maintenance not assessed.
Garthe et al. (2011) (Norway)	I: Mixed (national and tertiary) C: Mixed (national and tertiary)	I: 12 (10 M, 2 F) C: 9 (7 M, 2 F)	I: 18.5 ± 1.7 C: 19.6 ± 2.7	Enablement	I: Nutritional counselling meetings, prescribed diet plan and supplements, and access to sports products	I: Face-to-face	3 (~10 wks.) C: NR	No differences between groups 6 months post intervention and at 12 month follow up.

Study demographics				Intervention characteristics				Key findings
Publication (Country)	Sport (Level)	N (gender)	Age (years)	Intervention function	Intervention procedure (As reported by author)	Mode of delivery	Frequency* (duration)	
					C: Access to sports products			
Molina-López et al. (2013) (Spain)	I: Handball (professional) C: No control group	14 (NR)	I: 22.9 ± 2.7	Education	Education session	Unclear	1 (1 day)	Increased energy[a], carbohydrate[a] and monounsaturated fat[c] intake, decreased B vitamins[c] (thiamin, riboflavin, niacin and vitamin B_6) intake 8 wks. post intervention. Changes in energy[a], carbohydrate[a] and monounsaturated fat[c] intake were maintained 16 wks. post intervention with additional increased protein[c], vitamin D[c] and vitamin E[c] intake yet decreased calcium[c], potassium[c] and copper[c] intake.
Nascimento et al. (2016) (Brazil)	I: Mixed (national) C: No control group	Adults: 11 (M) Adolescents: 21 (15 M, 6 F)	Adults: 23.7 ± 0.5 Adolescents: 15.40 ± 0.4	Education and Enablement	Educational lecture, nutritional counselling consultations, and access to social media group	Face-to-face and internet. Educational lecture: unclear.	2 (~19-26 wks.)	Immediately post intervention; inadequate intakes of fruit[a] and vegetables[a] increased, adequate intakes of fruit[a] and vegetables[a] decreased. High intakes of sweets[c] decreased and adequate intakes of sweets[c] increased. High intakes of fats and oils[c] decreased and adequate intakes of fats and oils increased[c]. Adolescents increased meal frequency[c], and daily water intake[d] immediately post intervention. Maintenance not assessed.

Study demographics				Intervention characteristics				Key findings
Publication (Country)	Sport (Level)	N (gender)	Age (years)	Intervention function	Intervention procedure (As reported by author)	Mode of delivery	Frequency* (duration)	
Nowacka et al. (2016) (Poland)	I: Slalom canoeist (national) C: No control group	37 (29 M, 8 F)	F 16-27, M 16- 27	Education	Individual and group workshops and consultations	NR	NR	No difference for female group. Male group increased energy[a], carbohydrate[b], and fat[b] intake. Duration post intervention NR. Maintenance not assessed.
Philippou et al. (2017) (Cyprus)	I: Swimming (national) C: No control group	34 (11 M, 23 F)	15.2 ± 1.5	Education and Training	Athlete and parent interactive lectures and a supermarket tour	Face-to-face	1 (1 day)	Increased KIDMED Index score[e] (Median [IQR], pre 5.0 [4.0–7.0], post 7.0 [7.0–9.0]) consequent to a reduction in sweet and candy[d] intake and increased use of olive oil[d] 6 wks. Post intervention. Maintenance not assessed.
Rossi et al. (2017) (USA)	I: Baseball (tertiary) C: Baseball (tertiary)	I: 15 (M) C: 15 (M)	I: 19.3 ± 1 C: 19.8 ± 1.4	Education	I: Education session and reinforcements sessions C: Education session	Face-to-face	I: 2 (12 wks.) C: 1 (90 min)	Increased energy[b], protein[b] and fat[c] intake in intervention group immediately post intervention. Comparison of dietary intake against control was not assessed. Maintenance not assessed.
Valliant et al. (2012) (USA)	I: Volleyball (tertiary) C: No control group	I: 11 (F)	19.5 ± 1	Education	Meetings with registered Dietitian for individualised education following dietary assessments.	Face-to-face	2 (16 wks.)	Increased energy[a], protein[a] and carbohydrate[a] intake. Duration post intervention unclear. At follow up (duration NR) changes in energy[a] and protein[a] intake were maintained and carbohydrate[a] intake decreased.
Wenzel et al. (2012) (USA)	I: Volleyball (tertiary) C: Volleyball (tertiary)	I: 11 (F) C: 11 (F)	I: 19.8 (19-21) C: NR	Education and Enablement	I: Dietary counselling sessions following dietary analysis. Access to Dietitian between sessions. C: Passive controls	Face-to-face	2 (16 wks.)	Increased energy[a] intakes in favour of the intervention group. Increase in protein[a] and carbohydrate[a] intakes in the intervention group (comparison of macronutrients intake against control

Study demographics				Intervention characteristics				Key findings
Publication (Country)	Sport (Level)	N (gender)	Age (years)	Intervention function	Intervention procedure (As reported by author)	Mode of delivery	Frequency* (duration)	
								was not assessed). Duration post intervention unclear. Four months post intervention changes in energy [a] and carbohydrate[a] intake were maintained and protein[a] intake increased.

Notes: (I), intervention; (C), control; (F), female; (M), male; Tertiary, college or university athlete/team; wks., weeks; *, 1: 1 contact, 2: 2-5 contact, 3: >5 contact; NR, not reported; CBT, Cognitive Behavioural Therapy; Unclear, unclear description; a , below recommended requirements; b , met recommended requirements; c , above recommended requirements; d , recommended requirement was not set; e , KIDMEX score: poor, 0–3; medium, 4–7; good, 8–12; IQR, interquartile range.

Interventions characteristics

At least one intervention function was identified in each intervention. *Education* was described in 15/16 interventions, *Enablement* (5/16, e.g., providing athletes with sports products or counselling), *Training* (3/16), *Environmental Restructuring* (2/16), *Modelling* (1/16) and *Coercion* (1/16) (Additional file 3). The intervention provider was reported in seven studies with the most common involving a dietitian (Philippou et al., 2017; Valliant et al., 2012; Wenzel et al., 2012). Intervention setting was detailed in six studies and the most frequent location was a sports facility (Cleary et al., 2012; Costello et al., 2018; Doyle-Lucas & Davy, 2011). A summary of interventions characteristics can be found in Additional file 1: 1.3.

Behaviour change techniques

The 16 interventions contained an average of 3.7 BCTs (range 0 - 11). A total of 19 different BCTs were implemented across the interventions, of which four were reported only once. All coding and associated text are documented in Additional file 4, where active control groups were coded separately. The most frequently used BCTs in the intervention conditions were "Instruction on how to perform a behaviour" (13 studies), "Information about health consequences" (8 studies), and "Credible source" (7 studies) (Table 2). A summary of BCTs is presented in Additional file 1:1.4. The two active control conditions (Garthe et al., 2011; Rossi et al., 2017) contained one and three BCTs, respectively. BCT analysis by category and BCTs which were not identified are presented in Additional files 1:1.5 and 1.6, respectively.

TIDieR checklist

Reporting in the 16 interventions was adequate for 5/12 items (item 9 was applicable for individual interventions only) (Additional file 1:1.7). For the intervention conditions a brief description (16/16) and mode of delivery (9/16) were the most well reported items. Whereas, description of the procedure(s) (11/16), intervention setting (10/16), and materials used (10/16) were items with the most inadequate reporting. Moreover, all 16 studies scored inadequate for

assessment of fidelity (an evaluation of the delivery of the intervention as planned) and description of modifications at a study level.

Use of theory

Only three studies mentioned the use of theory (Abood et al., 2004; Costello et al., 2018; Doyle-Lucas & Davy, 2011) and these included Social Cognitive Theory (SCT), Health Belief Model (HBM) and the Behaviour Change Wheel (Abood et al., 2004; Costello et al., 2018; Doyle-Lucas & Davy, 2011). Abood et al. (2004) measured only one theoretical construct (self-efficacy) and thus was categorised as "Informed by theory" (Painter et al., 2008). The remaining two studies (Costello et al., 2018; Doyle-Lucas & Davy, 2011) applied two or more theoretical constructs and therefore are recognised as having "Applied theory" (Painter et al., 2008). It was not possible to categorise these two studies as "Testing theory" or "Building/creating theory" due to limited measurement and analysis of the theoretical constructs (Painter et al., 2008).

Table 2: BCTs used in sports nutrition interventions

BCT no.	BCT Label	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	Total
4.1	Instruction on how to perform a behaviour	✓	✓	✓		✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	13
5.1	Information about health consequences		✓			✓	✓	✓		✓	✓	✓		✓				8
9.1	Credible source						✓			✓		✓	✓	✓		✓	✓	7
12. 5	Adding objects to the environment					✓	✓			✓								3
3.1	Social support (unspecified)						✓					✓					✓	3
7.1	Prompts/cues						✓					✓			✓			3
6.1	Demonstration of the behaviour	✓												✓				2
5.3	Information about social and environmental consequences	✓		✓														2
2.2	Feedback on behaviour		✓														✓	2
12.1	Restructuring the physical environment					✓	✓											2
1.1	Goal setting (behaviour)						✓					✓						2
1.3	Goal setting (outcome)						✓			✓								2
2.4	Self-monitoring of outcome(s) of behaviour						✓			✓								2
5.2	Salience of consequences							✓							✓			2
2.3	Self-monitoring of behaviour									✓						✓		2

13.3	Incompatible beliefs	✓															1
2.7	Feedback on outcome(s) of behaviour						✓										1
1.5	Review behaviour goal(s)									✓							1
2.1	Monitoring of behaviour by others without feedback											✓					1
	Total Number of BCTs	4	3	2	0	4	11	3	1	8	1	7	1	4	3	3	4

Studies are listed in alphabetical order, (1) Abood et al. (2004); (2) Anderson (2010); (3) Buffington et al. (2016); (4) Chapman et al. (1997); (5) Cleary et al. (2012); (6) Costello et al. (2018); (7) Doyle-Lucas and Davy (2011); (8) Elias et al. (2018); (9) Garthe et al. (2011); (10) Molina-López et al. (2013); (11) Nascimento et al. (2016);(12)) Nowacka et al. (2016); (13) Philippou et al. (2017); (14) Rossi et al. (2017); (15) Valliant et al. (2012); (16) Wenzel et al. (2012).

Intervention effects on main outcome

One study had more than one intervention group (Buffington et al., 2016), and one study reported baseline and 6 and 12 month follow-up outcomes only (Garthe et al., 2011). Of the 16 studies reviewed, 13 showed significant changes in one or more dietary behaviour or nutritional intake variable (Anderson, 2010; Buffington et al., 2016; Cleary et al., 2012; Costello et al., 2018; Doyle-Lucas & Davy, 2011; Elias et al., 2018; Molina-López et al., 2013; Nascimento et al., 2016; Nowacka et al., 2016; Philippou et al., 2017; Rossi et al., 2017; Valliant et al., 2012; Wenzel et al., 2012). Within this sample of 13, five showed changes to be in accordance with recommended requirements (Anderson, 2010; Buffington et al., 2016; Elias et al., 2018; Nowacka et al., 2016; Rossi et al., 2017), four reported that recommended requirements were not met (Molina-López et al., 2013; Nascimento et al., 2016; Valliant et al., 2012; Wenzel et al., 2012), and the remaining four did not set recommended requirements (Cleary et al., 2012; Costello et al., 2018; Doyle-Lucas & Davy, 2011; Philippou et al., 2017). One study showed an adverse effect in favour of the intervention group (Chapman et al., 1997) and the remaining two studies reported no effect (Abood et al., 2004; Garthe et al., 2011). Of the six studies that has follow-up assessment points, four showed significant changes were maintained (Doyle-Lucas & Davy, 2011; Molina-López et al., 2013; Valliant et al., 2012; Wenzel et al., 2012). The follow-up ranged from 6 weeks – 4 months. The remaining two studies reported no effect at follow-up (Anderson, 2010; Garthe et al., 2011), 1 week and 12 months, respectively.

Influence of comparator group on intervention effectiveness

This research aimed to explore any relations between active, passive and no comparator group and intervention effectiveness. Of the three studies reporting no evidence of a significantly positive effect on the primary outcomes, two had a passive (Abood et al., 2004; Chapman et al., 1997) and one had an active control group (Garthe et al., 2011). Of the 13

interventions that demonstrated evidence of positive effect on at least one dietary behaviour outcome measure, only four had a passive comparator group (Anderson, 2010; Buffington et al., 2016; Doyle-Lucas & Davy, 2011; Elias et al., 2018). The remaining nine studies had no comparator group (Cleary et al., 2012; Costello et al., 2018; Molina-López et al., 2013; Nascimento et al., 2016; Nowacka et al., 2016; Philippou et al., 2017; Rossi et al., 2017; Valliant et al., 2012; Wenzel et al., 2012). A positive effect was found in all nine studies.

Behaviour change techniques and effectiveness

The most highly cited BCTs in effective interventions included: "Information about health consequences" (7/13), "Credible source" (7/13), "Prompts/cues" (3/13), and "Social support (unspecified)" (3/13). Additionally, "Instruction on how to perform a behaviour" occurred in 11/13 effective interventions, however this also appeared in 2/3 ineffective interventions. Furthermore, "Demonstration of the behaviour" was reported in 3/13 effective interventions yet was also present in 2/3 ineffective interventions.

Discussion

To our knowledge this is the first systematic review to investigate the reported effectiveness of nutritional interventions attempting to change eating patterns among athletes. This review has identified 16 interventions that currently represent the best available evidence for sports nutrition. Adopting a novel and robust approach, this review has extracted six function categories and 19 different BCTs that characterise the interventions in this field. By revealing intervention content this review provides translational evidence to improve research, intervention design, and service delivery (Michie, Fixsen, et al., 2009).

Our narrative synthesis shows that interventions aiming to improve the dietary intake of athletes were reported to be effective in promoting behaviour change and in some instances, behaviour change maintenance. The most commonly deployed BCTs were; "Instruction on how to perform the behaviour" and "Information about the health consequences". However,

these BCTs were found in effective and ineffective interventions, and therefore the equivocal nature of these findings exposes the uncertainties of behaviour change strategies within sports nutrition interventions. Consequently, caution must be taken when interpreting the value of these BCTs within sports nutrition. By seeking to understand the behavioural strategies used within this field, this review has highlighted that at present, there is an insufficient evidence-base to identify the active components of effective sports nutrition interventions.

According to behavioural science, theory helps to identify the elements that are essential by predicting the changes to be expected and detailing how change is achieved (Craig et al., 2013). This review illustrates a lack of robust theoretical underpinning within sports nutrition interventions. Without a sound theoretical basis that provides a rationale for the design of an intervention and the criteria for its success, it is difficult to evaluate empirical evidence. Further, the application of theory offers a systematic approach to the design and development of an intervention, providing extensive ways for targeting behaviour change through a plethora of BCTs (Cane et al., 2015). Only 19 BCTs are currently employed within sports nutrition interventions suggesting that 80% of the available BCTs are not being used. Drawing upon well-established behaviour change research within physical activity, a broader spectrum of BCTs are applied (Cradock et al., 2017). The techniques identified as effective include; demonstrating the behaviour, using prompts and cues, prompting behavioural practice, setting graded tasks, and rewarding process (Howlett, Trivedi, Troop, & Chater, 2018; Olander et al., 2013). Critically, some reputable BCTs were noticeably absent in this review, including "action planning" which highlights the importance of self-regulation, forming the essence of several behaviour change theories (Bandura, 1991; Rosenstock, Strecher, & Becker, 1988). "Identity" also represents an opportunity for behaviour change (French, Olander, Chisholm, & Mc Sharry, 2014; West, Walia, Hyder, Shahab, & Michie, 2010), embodying one of the strongest drivers for change associated with positive health outcomes (Gray et al., 2013; West et al., 2010), as

has BCTs using automatic processes such as “habit formation” and “habit reversal” (Carels et al., 2014). The BCTTv1 provides a standardised vocabulary for intervention components (Abraham & Michie, 2008) and is the only framework that provides a method for evaluating the active ingredient(s) of a behavioural intervention (Michie, Fixsen, et al., 2009). Thus, application of BCTs has the potential to accelerate the science of behaviour but this review highlights that this potential has not been realised in the sports nutrition field to date. The authors therefore call upon the sports nutrition field to act on the UK Medical Research Council’s framework for complex interventions and develop theory informed interventions (Craig et al., 2008). To support this advancement in professional practice the development of guidelines to facilitate sports nutritionists in the application of behavioural science seems warranted. Scholars argue the adoption of theory should be a scientific priority (Craig et al., 2008; Michie & Abraham, 2004) and thus it is recommended that interventions are no longer informed by theory or apply elements of theory, instead intervention designers should aspire to test or build the theory they adopt (Painter et al., 2008). Until then, the active ingredients for change will remain unknown.

Michie and colleagues state behaviour is a function of the interface and the interaction between capability, opportunity, and motivation (Michie et al., 2011). Research suggests that targeting multiple levels of these behavioural influences can increase the likelihood of behaviour change. However, intervention constructs should clearly link to an overarching analysis of the target behaviour (Michie et al., 2014; Michie et al., 2011). Sports nutritionists and researchers in the field are therefore encouraged to conduct a detailed behavioural diagnosis prior to designing their interventions in order to maximise the likelihood of the intervention aims being realised. Specifically, the application of the COM-B model (Michie et al., 2011) allows researchers to identify deployable techniques to address certain behavioural deficits identified, enhancing the robustness and efficiency of future sports nutrition

interventions. For example, “instruction on how to perform a behaviour”, “demonstration of the behaviour’, and “behavioural practice/rehearsal” have been reported to play a collective role within diet and physical activity interventions (Dombrowski et al., 2012; French et al., 2014; Hartmann-Boyce, Johns, Jebb, & Aveyard, 2014). Yet, “behavioural practice/rehearsal” was notably absent from all reviewed studies. Given evidence points to the synergist effects of all three BCTs being deployed together (Cradock et al., 2017) due to their theoretical underpinnings (Michie et al., 2013), this is worth considering in future sports nutrition interventions. Therefore, using this as a starting point, the design of future interventions may incorporate specific BCTs or groups of BCTs to examine their effectiveness in sport nutrition programmes.

In line with other reviews of dietary behaviour interventions (Hartmann-Boyce et al., 2014; Martin, Chater, & Lorencatto, 2013), the application of the TIDieR checklist highlighted the reporting of sports nutrition interventions requires substantial improvement. Important points for intervention design include a detailed description of the processes, activities, and procedures that will be carried out, along with the materials that will be used, and the intervention location(s) (Hoffmann et al., 2014). Intervention designers are encouraged to consider reporting guidelines at the outset of intervention design and development. The use of reporting guidelines aligns with other authors who have encouraged journals to endorse the use of the TIDieR and WIDER (Workgroup for Intervention Development and Evaluation Research) (Albrecht, Archibald, Arseneau, & Scott, 2013) checklists, in a similar way to CONSORT and related statements (Atkins & Michie, 2013; Hoffmann et al., 2014). Endorsed and implemented reporting guidelines facilitate authors, reviewers, and publishers to be completely transparent when describing methods and findings. Doing so will enhance our ability to replicate and build on research findings, which ultimately has the potential to increase the impact of research on changing athletes’ dietary behaviours.

The variability in the primary outcome measure restricts our ability to establish effectiveness and thus fully understand the impact of sports nutrition interventions. Within this review some studies found improvements in discreet outcome variables (e.g., changes in milk/candy score) (Doyle-Lucas & Davy, 2011), whereas others found changes across a broad range of outcome variables (e.g., macronutrients/micronutrients intake) (Anderson, 2010). This suggests caution should be taken when interpreting the effectiveness of some interventions included in this review and this cautionary tale is noted within other reviews of dietary behaviour and physical activity interventions (Howlett et al., 2018; Michie, Abraham, Whittington, McAteer, & Gupta, 2009) owing to an inability to quantify behavioural change. Establishing a definition for "dietary intake" and enhancing the validity and reliability of dietary assessment methods (Burke, 2015) are crucial for ongoing efforts to build a body of evidence to establish what interventions work with what behaviours, for whom, and why. Therefore, the authors call for experts to come to a consensus on how to assess for effectiveness in the sports nutrition field.

Strengths and limitations

The strengths of this review include the comprehensive terms and databases searched, the pre-registration, and adherence to the PRISMA guidelines. Additionally, this is the first review to incorporate coding of the TIDieR guidelines against published sports nutrition intervention descriptions. Some limitations also warrant mention. Coding of the BCTs depended on the intervention reporting quality, quantity, and accuracy. For instance, a study in smoking interventions showed that 44% of BCTs failed to feature in the published reports (Lorencatto et al., 2012). Reporting inconsistencies was inherently problematic in this field which may have resulted in an incomplete picture of some interventions. Assessment of fidelity was noticeably absent from all studies, therefore it was not possible to determine if the interventions were implemented, received, or enacted as intended (Borrelli, 2011). All studies

used dietary intake self-reporting tools, limitations of which are known to be amplified when attempting to assess intervention effectiveness (Lara et al., 2014), as by necessity, study participants are aware of the expected dietary behaviour, which can introduce reporting bias (Adamson & Mathers, 2004).

Conclusion

Overall the findings of this comprehensive review of sports nutrition interventions provide new perspectives on the design, development, and evaluation of sports nutrition interventions. Specifically, adoption of the TIDieR guidelines would vastly improve the ability for researchers, practitioners, and policy makers to interpret and replicate effective interventions. This would be of benefit if details of intervention procedures and structuring the description of content using the BCTTv1 were considered. While the findings of this review serve to equip sports nutrition practitioners and researchers with the understanding to improve the reporting of their programme components and intervention outcomes, future research is needed to establish the effectiveness of behavioural science application in the optimisation of sports nutrition provision and the protection of athletes' health, wellbeing, and performance. We hope this review will become a key reference for the field by introducing those working in sports nutrition to the tools and theories that may help them to design and disseminate sports nutrition interventions for athletes who are not meeting their nutritional requirements for optimal health and performance.

Authorship

MB and SB formulated the research question, designed the study and defined the search terms. MB carried out the electronic searches. MB and NM carried out the screening of articles and SB resolved discrepancies. MB extracted all data. MB and SB carried out BCT and TIDieR coding. MB analysed all data and drafted the manuscript with SB. All authors approved the final version of the paper.

Conflicts of interest

The authors declare that they have no conflict of interest.

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